

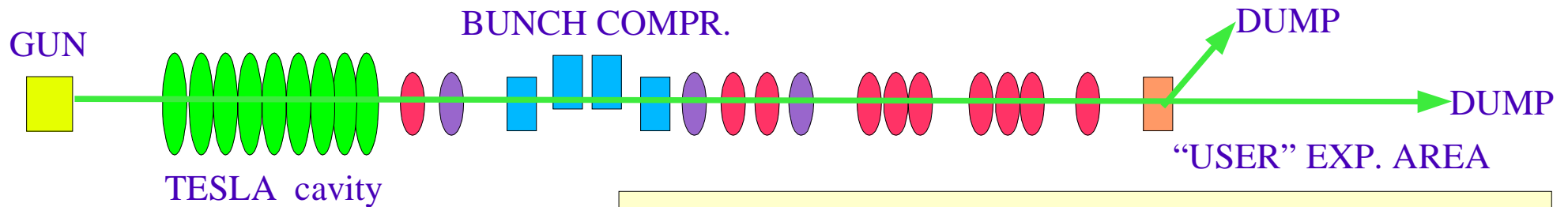
# The Fermilab/ NICADD Photoinjector Laboratory



- Production, manipulation, and characterization of high-brightness e-beams
- Development of new diagnostic techniques
- Advanced Accelerators (plasma/laser)
- Polarized rf-gun R&D



# The FNPL injector



- ✓ Extensive diagnostics suite for beam dynamics studies,
- ✓ FNPL control system allows **remote operation** by off-site team (DESY, LBNL, Univ. Michigan,...)

## Typical parameters:

P	15-16 MeV/c
Trans. $\epsilon$	3.7 mm-mrad @ 1nC
	12.6 mm-mrad @ 8nC
$\delta p/p$	0.25 % @ 1nC
$I_{\text{peak}}$ (BC OFF)	~75-330 A
$I_{\text{peak}}$ (BC ON)	~218-1740 A

## Past year activities:

- ✓ Generation and study of flat beams
- ✓ Commissioning of new diagnostics
- ✓ Improvement of operation/modeling of the beamline
- ✓ Observation of plasma-based acceleration

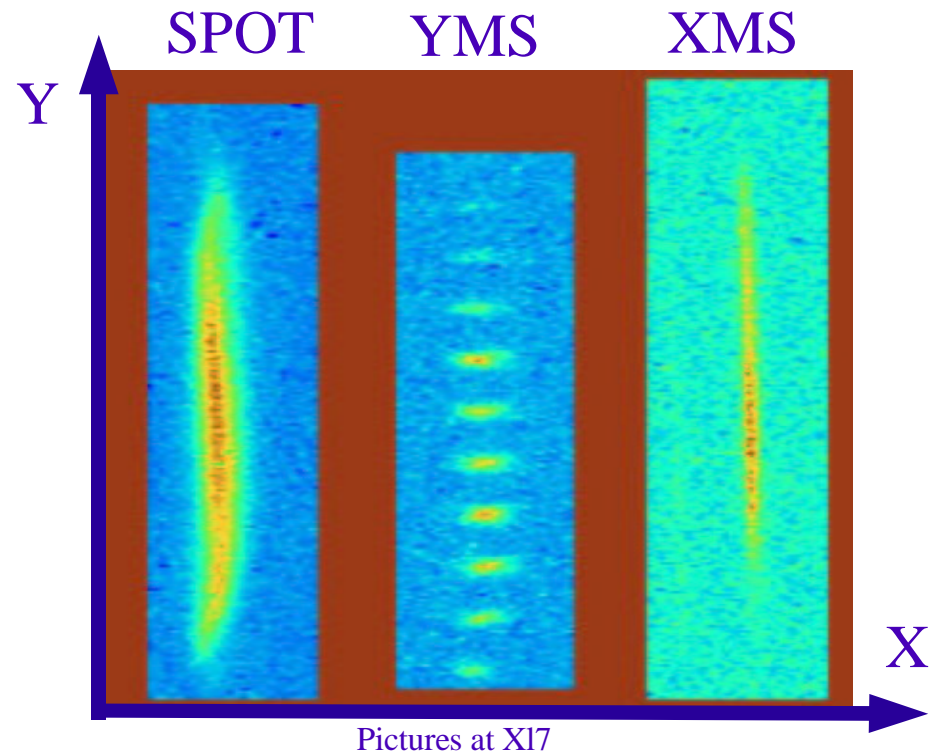
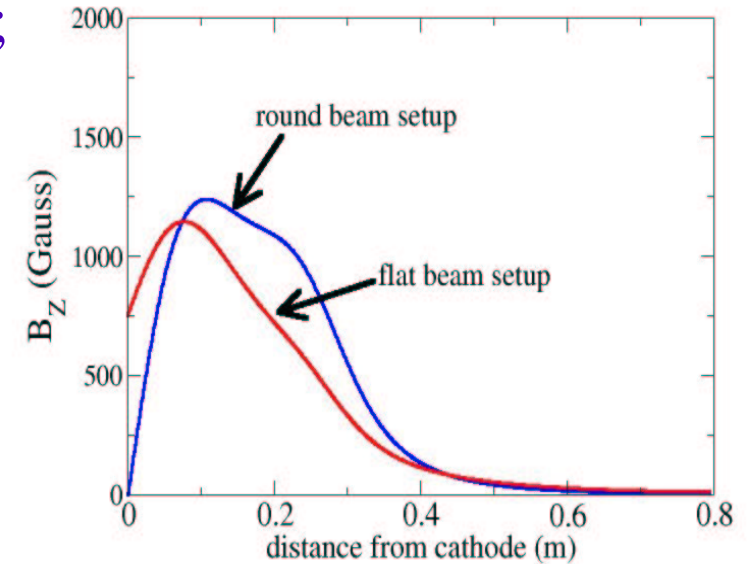
# Generation/Study of flat beams

Flat beams for LCs obtained in damping rings; for e- they can be generated out of the injector.

- ✓ Photocathode is immersed in a B-field
- ✓ Solenoid fringe field → beam acquires an kinematic angular momentum (fully x-y coupled motion)
- ✓ A skew quad. channel decouples the motion and yields a beam with a high transverse emittance ratio :

$$\frac{\epsilon_x}{\epsilon_y} \propto B_z^2$$

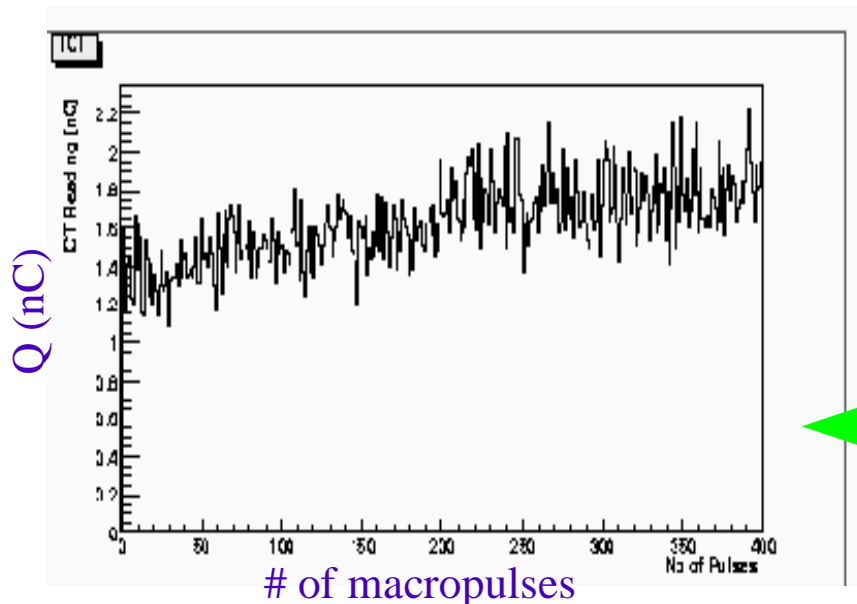
Best emittance ratio achieved to date:  
 $(\beta\gamma\epsilon_y)/(\beta\gamma\epsilon_x) = 45/0.9 \text{ mm-mrad} = 50$   
 for  $Q=0.5 \text{ nC}$



Pictures at X17

# Rf-gun studies

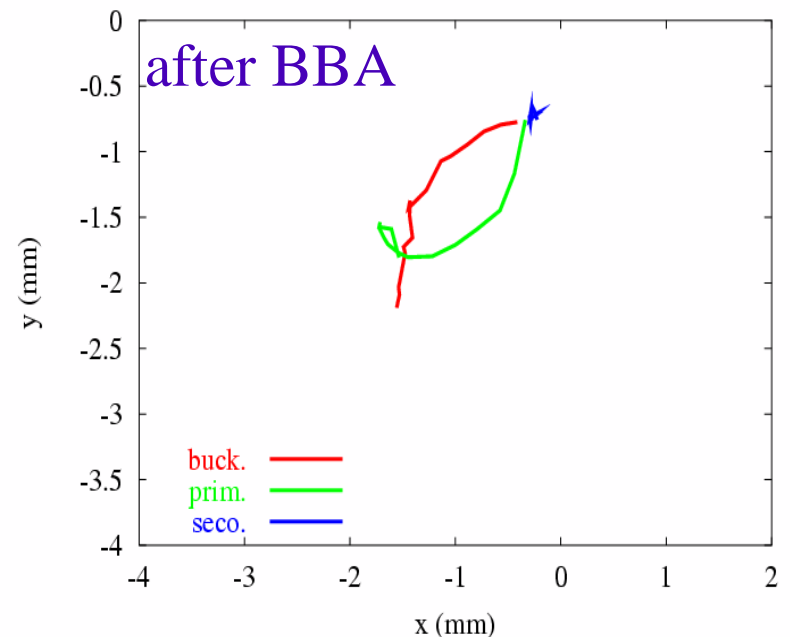
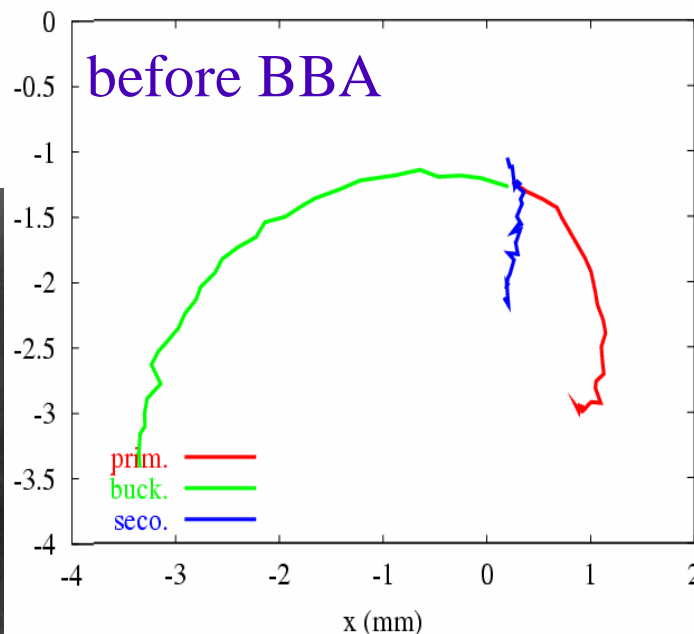
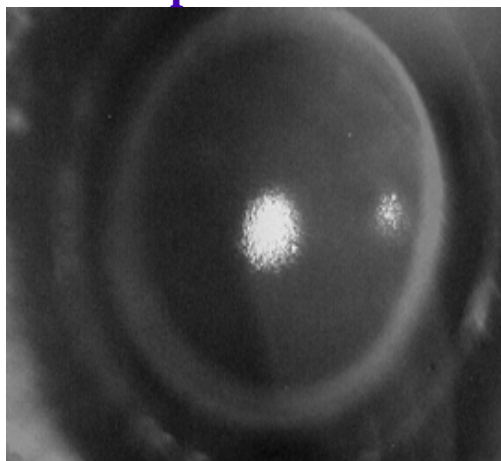
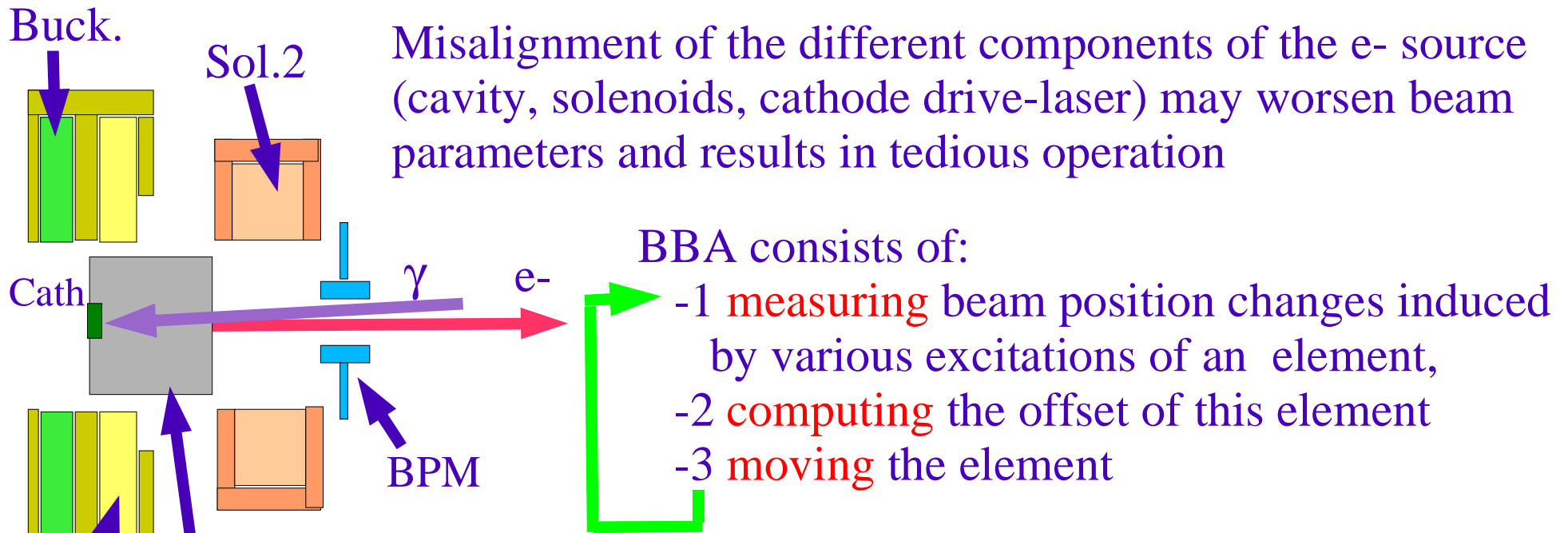
- ✓ Study of rf-breakdown rate in long rf-macropulse and test of a method to significantly reduce the breakdown rate (by shaping the "turn-on" of the rf-pulse)
- ✓ Using a set of microphones placed on the rf-gun cavity, investigated the origin site of rf-breakdown (origin is the rf-coupling slot)
- ✓ Experimental exploration of *in situ* "rejuvenation" of photocathode using a multipacting-based processing technique



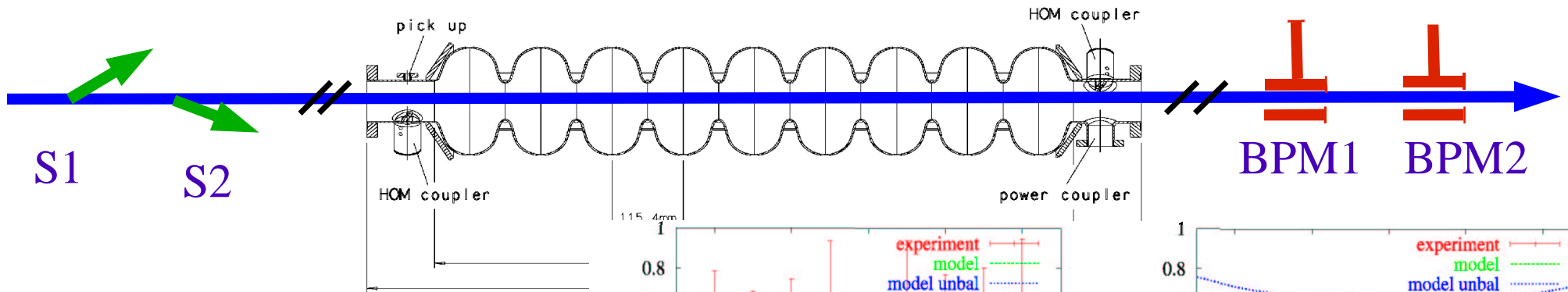
After 600 "multipacting macropulses" the charge increased by a factor  $\sim 2$ .

Only last 400 pulses are displayed

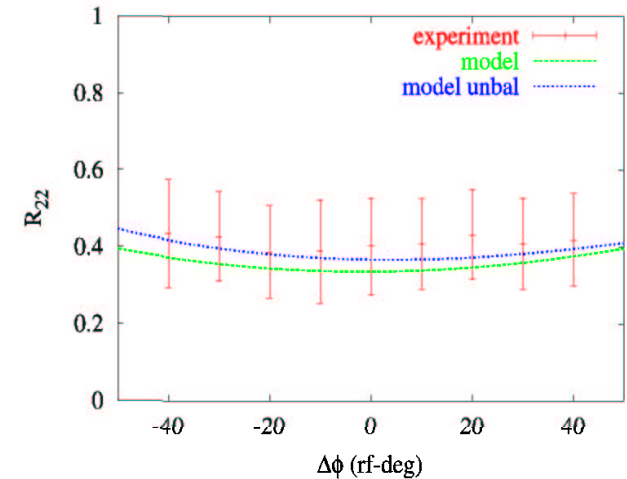
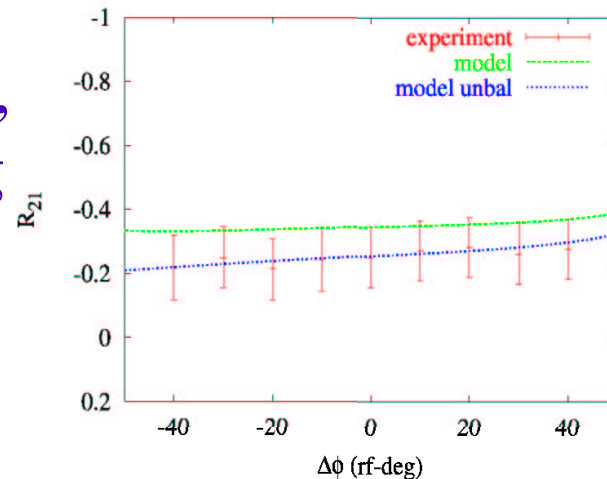
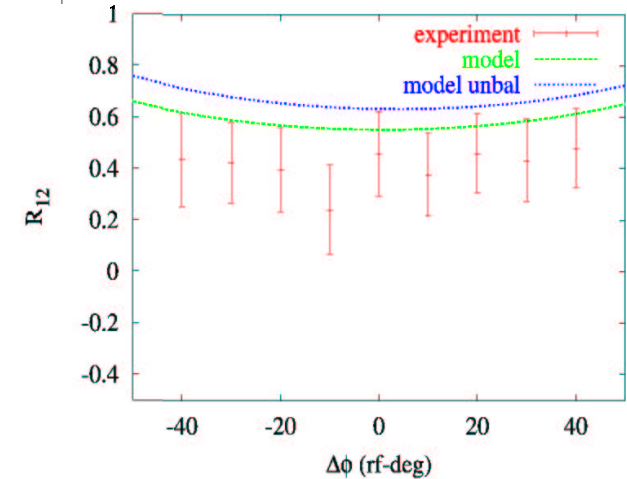
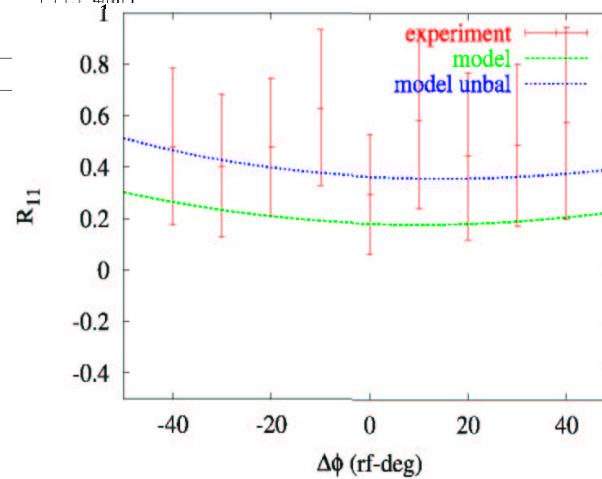
# Beam-based alignment of e-source components



# Measurement of TESLA cavity Transfer matrix



- ✓ 2 steerers to vary initial beam position at cavity entrance
- ✓ 2 BPMs downstream to infer orbit response at cavity exit
- ✓ Agreement not perfect, transfer matrix modeling for non-perfectly flat field profiles on-going



# Frequency-domain bunch length diagnostics

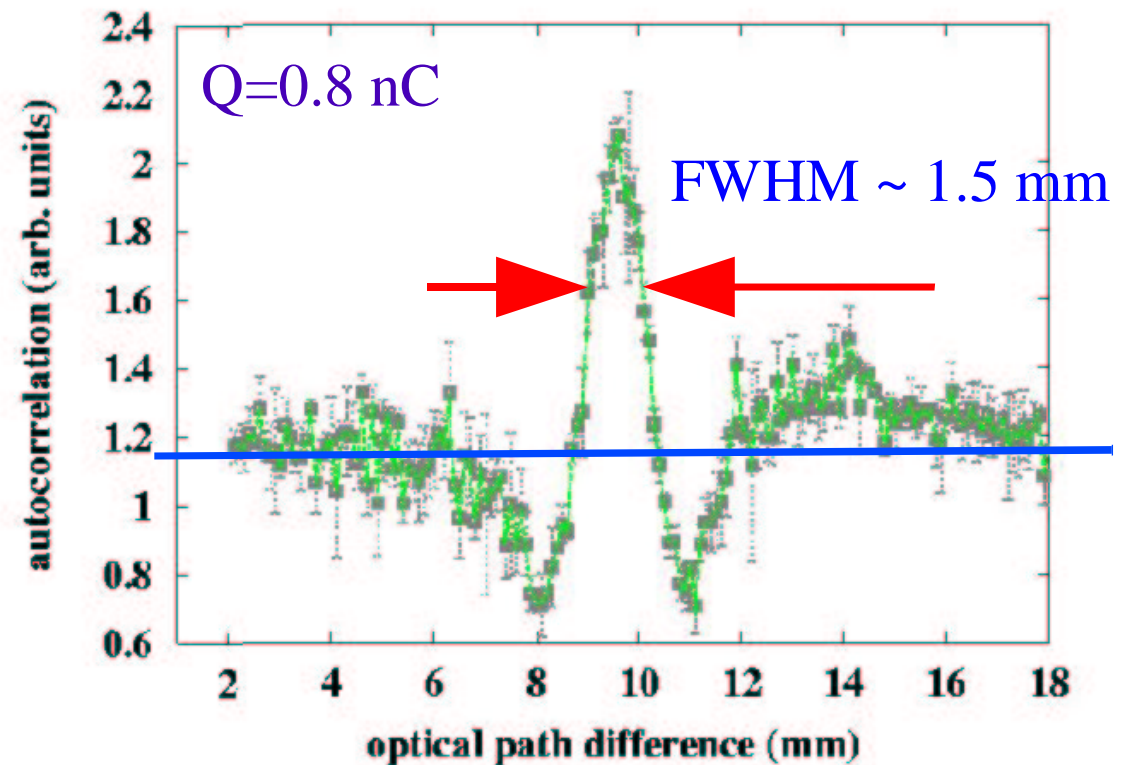
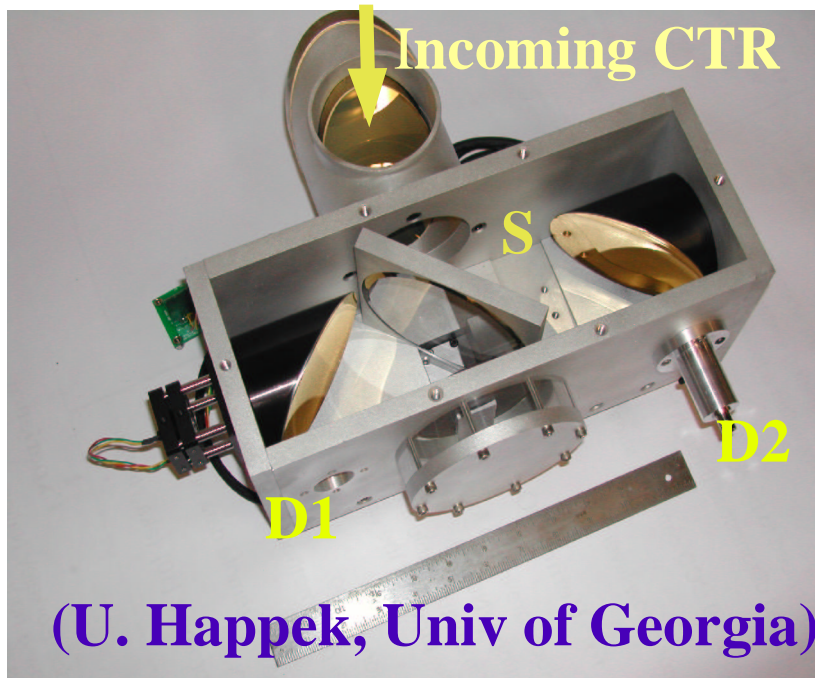
- ✓ Electrons in a bunched beam can radiate coherently at wavelengths  $\lambda > \sigma_z$
- ✓ Radiated pulse mirrors long. bunch distribution
- ✓ Interferometry of transition radiation

Total radiated energy by N e- :

$$W_{Ne}(\lambda) = W_{1e}(\lambda) (N + N(N-1)|f(\lambda)|^2)$$

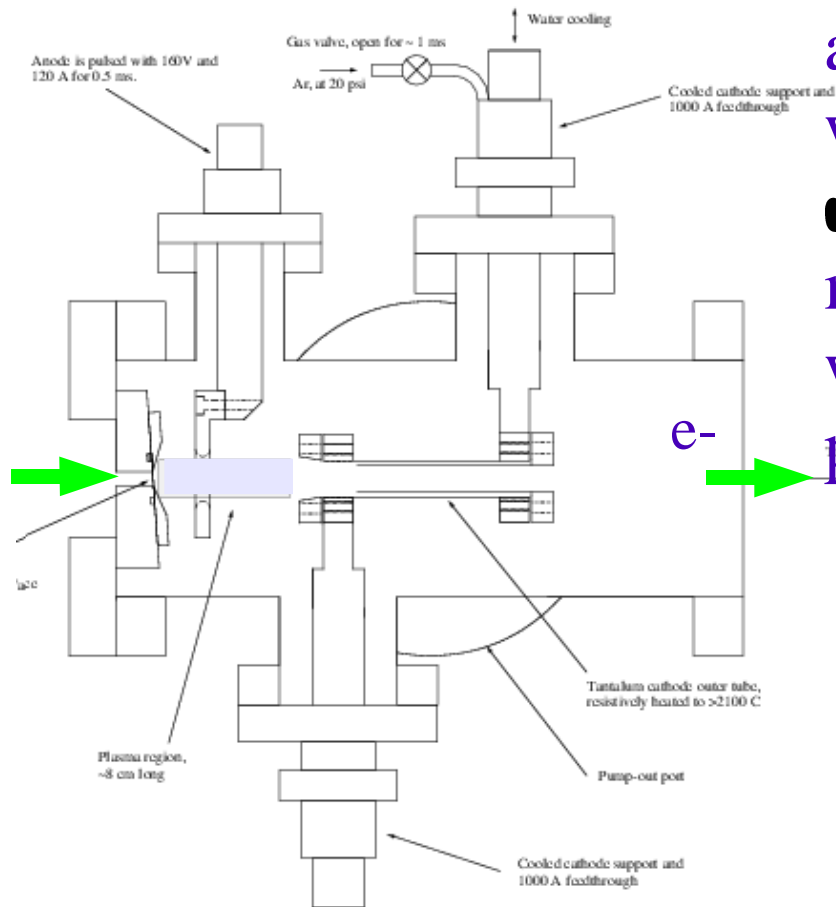
Energy radiated  
by 1 electron

Bunch form factor



# Plasma wakefield acceleration

The plasma device

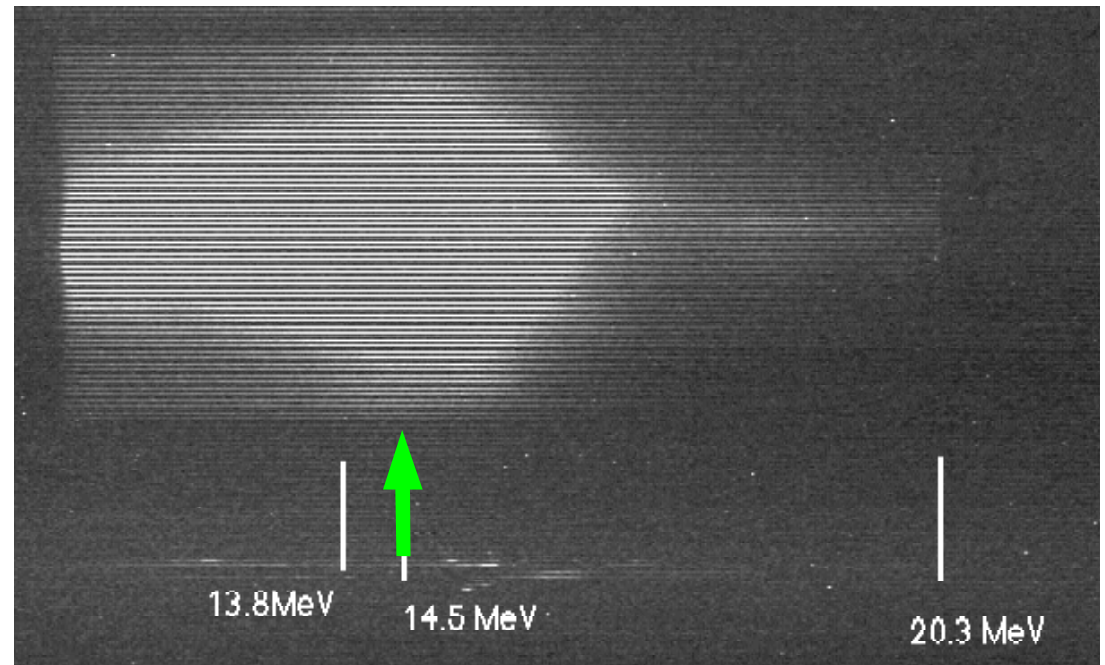


✓ High peak current e- beam injected in a plasma induced density modulation waves

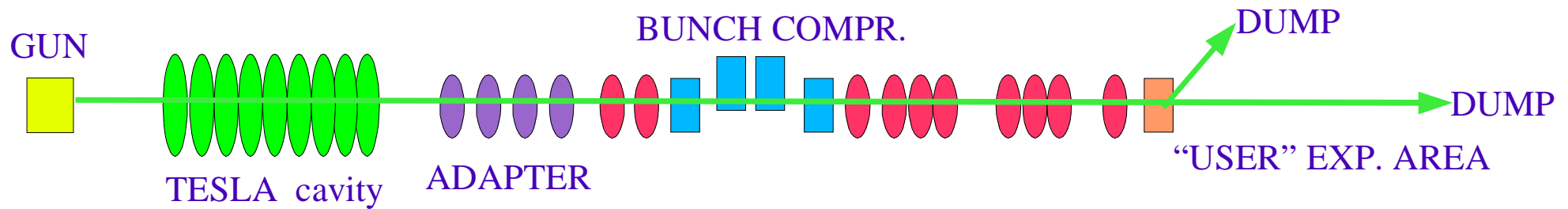
✓ Electrons energy along the bunch is modified accordingly to the induced wake-field, energy gain can occur for part of the bunch

6-8 nC,  $10^{14}/\text{cc}$  plasma, 1 mm  $\sigma_z$   
Recent results indicates an  
accelerating field of  $\sim 100$  MV/m  
has been achieved

(N. Barov et al., NIU)

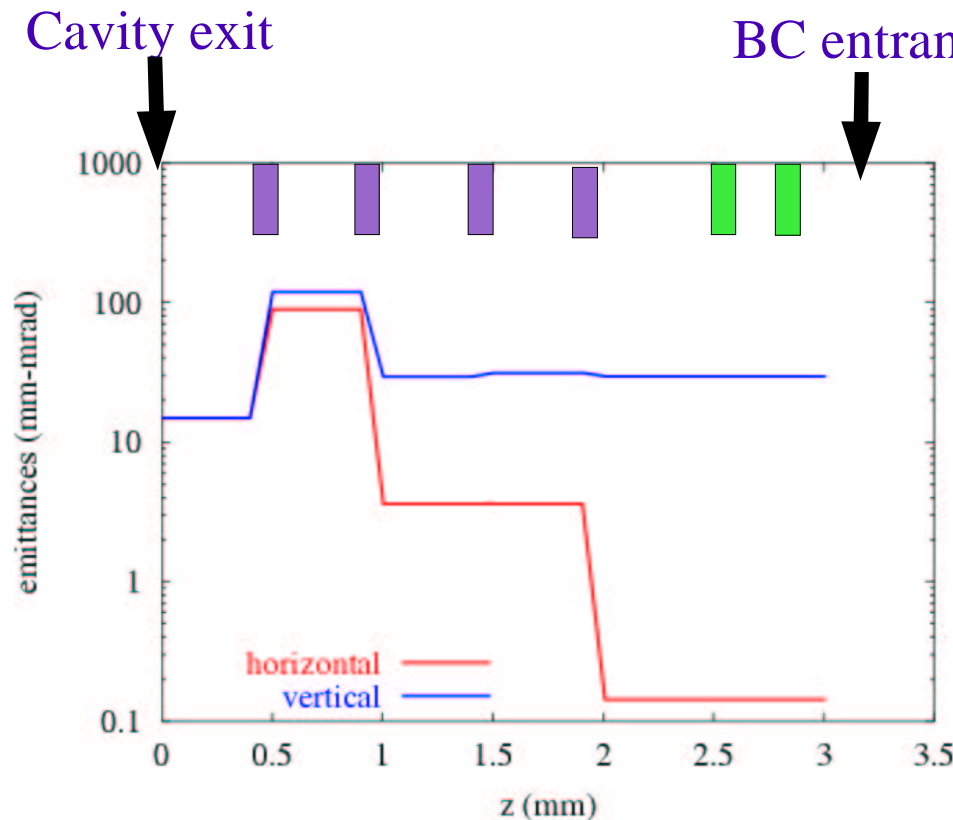


# Short term upgrade of FNPL



- ✓ Improved emittance ratio in the flat beam configuration
- ✓ Bunch compression of flat beam possible
- ✓ Reconfiguration + addition of diagnostics
- ✓ Accommodate new experiments

# New setup for flat beams



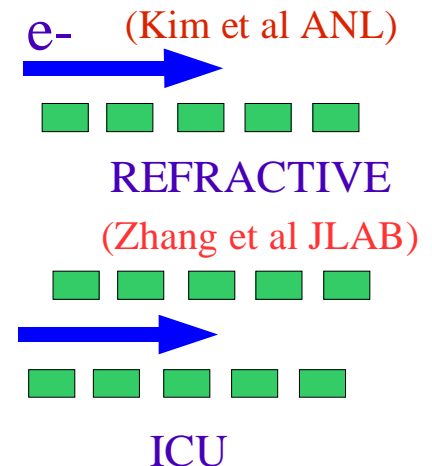
✓ New round-to-flat adapter

✓ Expect  $\epsilon_x/\epsilon_y \sim 150-200$

✓ Continue parametric studies of flat beam properties (especially emittance compensation)

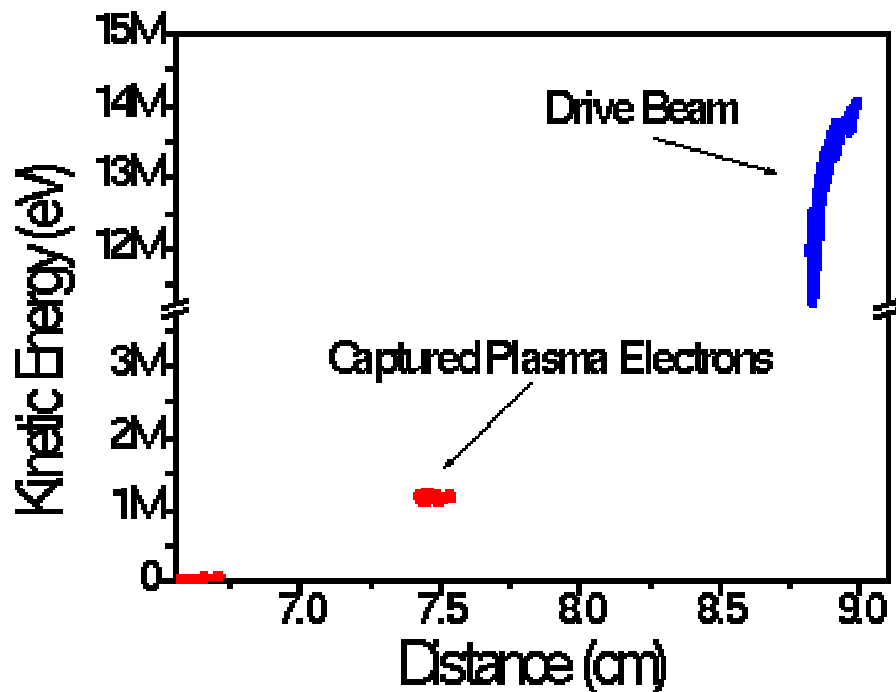
✓ Study of emittance growth during compression versus “beam flatness”

✓ Compressed flat beams have applications in SASE Smith-Purcell radiation sources (in refractive mode or “image charge undulator”) to generate FIR ps-pulses

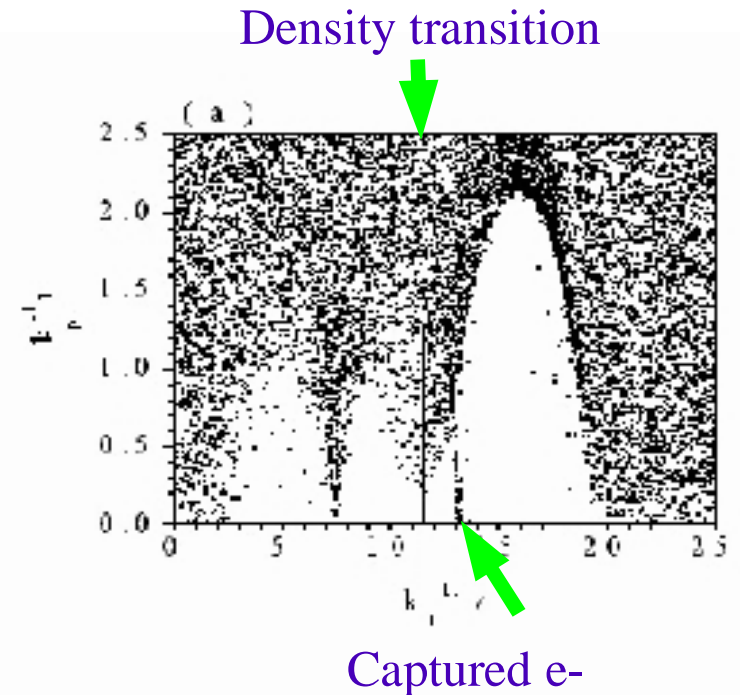


# Plasma density transition trapping

- ✓ Self-trapping mechanism based on rapid change in the wakefield wavelength at a steep drop in the plasma density
- ✓ Plasma electrons are dephased into an accelerating field of the plasma wake



(M. Thompson et al., UCLA)



Assumed parameters for drive-beam:

$E = 14 \text{ MeV}$

$Q = 5.9 \text{ nC}$

peak plasma density  $= 2.10^{13} \text{ cm}^{-3}$

Captured beam parameters:

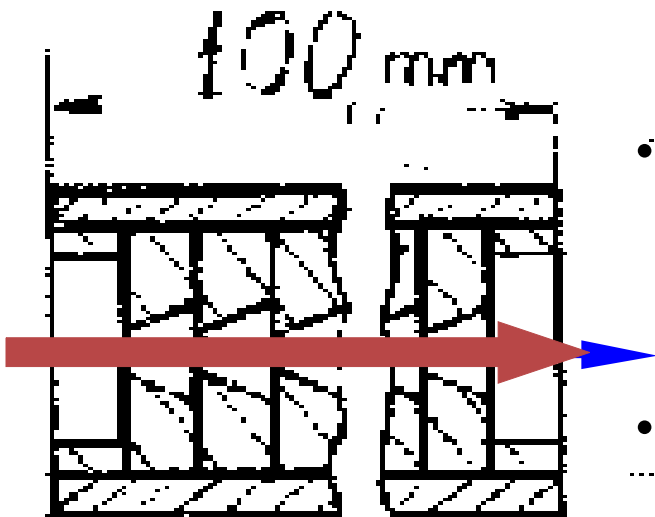
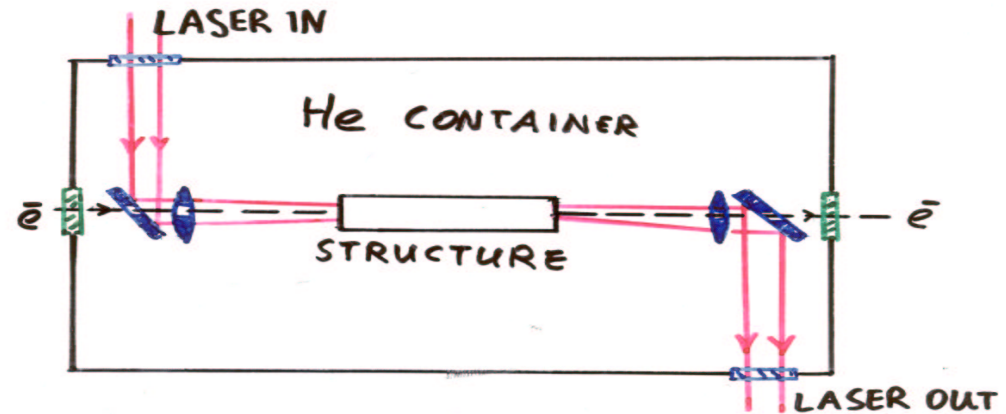
$E = 1.2 \text{ MeV}$

$Q = 120 \text{ pC}$

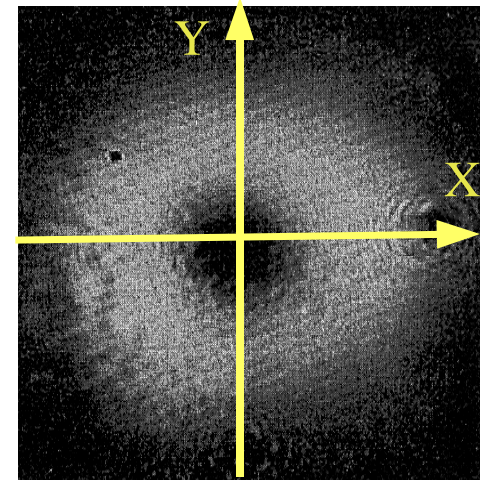
$\delta (\text{total}) = 11 \%$

# Laser acceleration

- Laser beam is used to provide longitudinal accelerating E-field
- laser and e- beams are “coupled” in the “open iris structure” (radius  $\gg \lambda$ )



- Laser operates in the  $TEM_{01}^*$  mode, since it provides the largest possible Ez-field.
- $TEM_{01}^*$  generated from  $TEM_{01}$  mode via a Mach-Zehnder interferometer

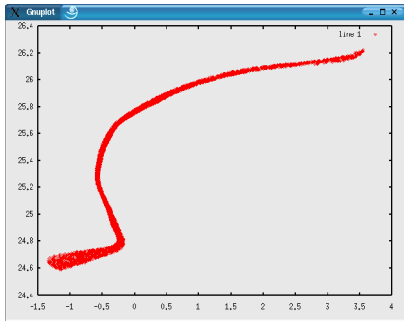


- For a laser peak power of 34 TW  $\longrightarrow$   $E_a = 0.54$  GV/m
- At FNPL anticipated energy gain of 2.5 MeV (R. Tikhoplav et al., Rochester)

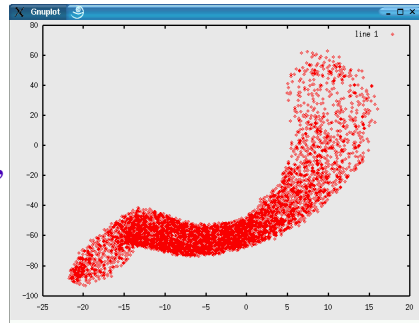
# Test of dipole-mode and 3<sup>rd</sup> harmonic accelerating cavity

- 3.9 Ghz dipole mode cavity developed for CKM experiment in main injector

(z,  $\delta$ ) after bunch compressor

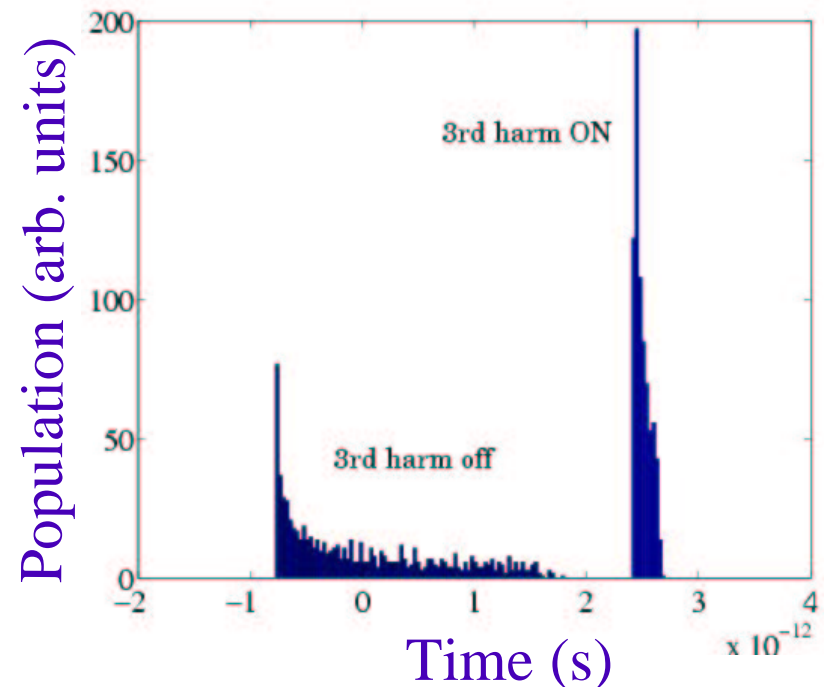


(x, y) at spectrometer,  
cavity deflecting vertically,  
horizontal axis is  $\delta$



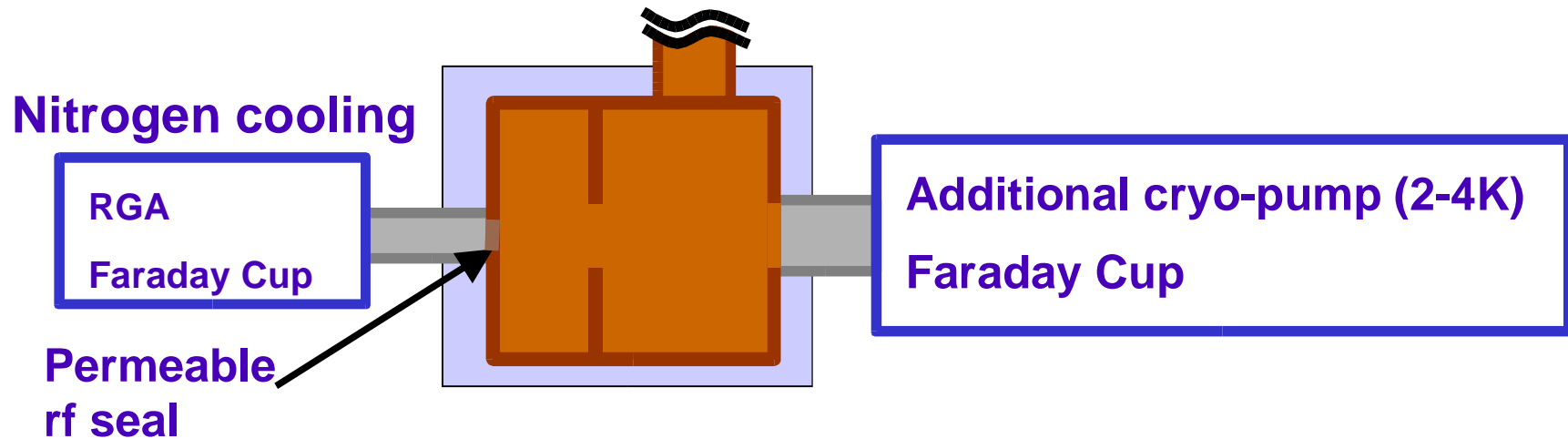
- 3.9 Ghz accelerating mode cavity, developed to remove longitudinal phase space distortions and increase the peak current

- Cavity will be tested in FNPL and will provide a unique diagnostics to study slice parameters along the bunch (e.g.  $\epsilon$ ) and reconstruct long phase space
- Cavity in conjunction with transverse collimation can be used to generate ultra-short bunches



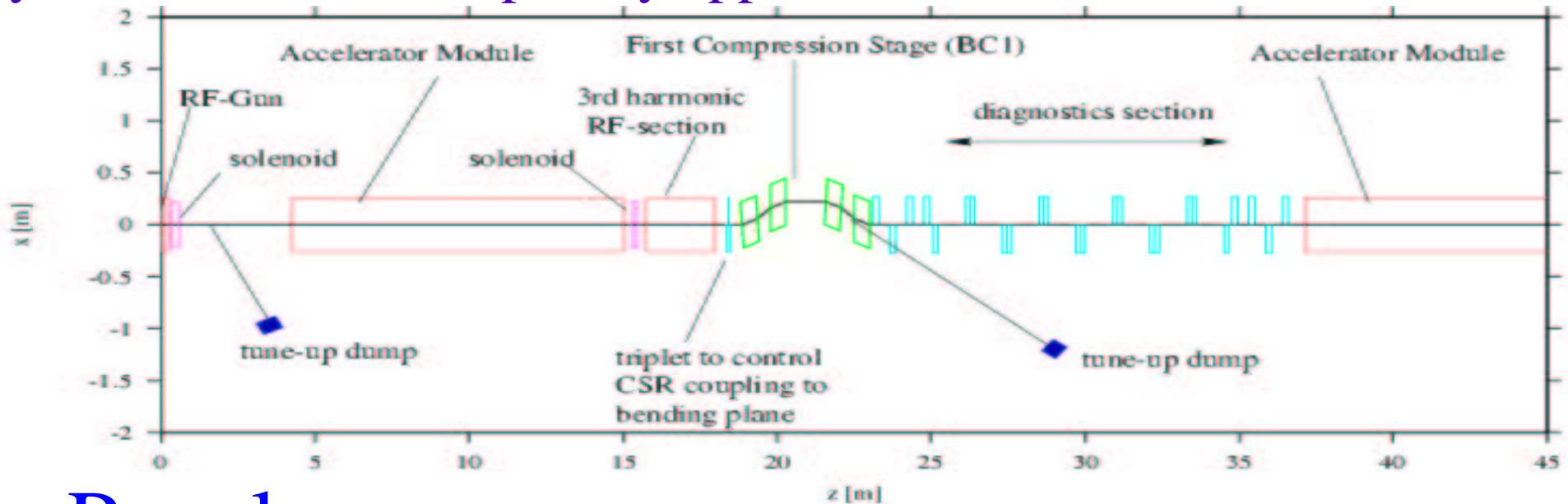
# R & D for polarized rf-gun

- ✓ Improve rf-gun to enable generation of polarized beams:
  - Vacuum pressure  $<10^{-12}$  Torr
  - GaAs photocathode in rf-gun
  - lifetime and dark current studies
- ✓ Use spare rf-gun to explore the use of **cryogenic N-cooled cavity**



# Longer term project plan

✓ Increase beam energy consistent with a fully integrated injector system for multi-disciplinary applications



## People

N. Barov, NIU

K. Bishofberger, UCLA (gr. s)

C. Bohn, NIU/FNAL

K. Desler

D. Edwards

H. Edwards

M. Huening

D. Mihalcea, NIU

P. Piot

J. Santucci

Y.-E. Sun, U. Chicago (gr. s)

R. Tikhoplav, U. Rochester (gr. s)

### Active at a distance:

J.-P. Carneiro, DESY

K. Floettmann, DESY

U. Happek, U. Georgia

W. Hartung, MSU

S. Lidia, LBNL

D. Sertore, INFN-Milano

M. Thompson, UCLA (gr. s)

S. Wang, U. Indiana (gr. s)

# Summary

## Past month activity:

- ✓ Continued flat beam studies
- ✓ Improved operation + model of the accelerator with the help of new diagnostics (BPM, bunch length)
- ✓ Plasma acceleration was observed

## Upgrade planned in April/May 2003:

- ✓ Continue flat beam study with an improved set-up
- ✓ Study the compression of flat beam + applications
- ✓ Plasma-based e- source will be installed by the summer
- ✓ Install “open iris structure” for laser acceleration after the plasma source experiment is completed

## Longer term projects:

- ✓ Beam test of the CKM and 3<sup>rd</sup> harmonic cavities
- ✓ R&D on polarized rf-guns
- ✓ Energy upgrade
- ✓ Gun development